Revised Conceptual Site Model
Wyckoff OU-1 Focused Feasibility Study Project Area

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1. Introduction

This technical memorandum presents preliminary revised conceptual site model (CSM) for the Focused Feasibility Study (FFS) Project Area of the East Harbor Operable Unit (EHOU, also designated as OU-1), Wyckoff Eagle Harbor Superfund Site (Site) on Bainbridge Island, Washington. CH2M HILL prepared this technical memorandum to support the FFS task for Region 10 Architecture and Engineering Services (AES) Contract No. 68-S7-04-01, Task Order 077-RI-FS-10S1. This revised CSM updates the December 27, 2012 preliminary CSM and is subject to further evaluation revision as the FFS is developed.

1.1 Purpose and Document Organization

The purpose of this technical memorandum is to present and update CSM concepts related to the source and migrations pathways of nonaqueous phase liquid (NAPL) contaminated sediments present in the intertidal sediments of the OU-1 FFS Project Area (Figure 1-1). NAPL occurrence in OU-1 sediments is related to historical use and releases of creosote from wood treatment and handling operations at the Wyckoff facility.

This technical memorandum includes the following sections:

- **Section 1, Introduction**: Describes the purpose of this technical memorandum and defines the FFS Project Area.
- **Section 2, Site Background**: Presents background about the Wyckoff Eagle Harbor Site and the OU-1 FFS Project Area.
- **Section 3, Site Characterization**: Presents an overview of the existing site characteristics for the FFS Project Area including site setting, site sediments, general groundwater occurrence, NAPL distribution, and general coastal environment.
- **Section 4, Conceptual Site Model**: Presents the CSM for the FFS Project Area including NAPL transport, NAPL characteristics and NAPL fate and transport.
- **Section 5, References.**

Figures and tables are attached to this technical memorandum to support the sections above.

Information presented in this CSM is intended to form the basis for text sections, tables, and figures to be included in the forthcoming OU-1 FFS. Using this information along with candidate remedial technologies and process options described in the October 18, 2013 *Wyckoff OU-1 Remedial Alternatives Technology Screening Technical Memorandum* (CH2M HILL 2013a), the FFS will evaluate remedial alternatives addressing sediment NAPL contamination in the Project Area.

1.2 FFS Project Area Description

The FFS Project Area is 10.8 acres and includes intertidal portions of the East Beach and North Shoal areas and a small portion of the West Beach in OU-1 (Figure 1-1). The Project Area limits are defined by locations with historical near-surface NAPL occurrences within intertidal areas most frequented by recreational users. The general marine setting of the Project Area consists of beach and tideflat environments seaward of the existing sheet pile containment wall installed around the Wyckoff upland facility. Surface elevations within the FFS Project Area range from approximately 0 to -1 foot mean lower low water (MLLW) to about 15 feet MLLW toward the sheet pile wall and upper beach areas. The MLLW datum is derived from the arithmetic mean of the lower low water heights of the tide as observed over the 19-year National Tidal Datum Epoch. Additional tidal reference elevations are presented in this preliminary revised CSM, tables and figures with respect to the MLLW reference datum of elevation 0 feet:

- Highest Observable Tide (HOT) Elevation: 14.5 feet
- Mean High Water (MHW) Elevation: 10.5 feet
- Mean Low Water (MLW) Elevation: 2.8 feet
- Lowest Observable Tide (LOT) Elevation: -5.0 feet

2. Site Background

The Wyckoff Eagle Harbor Superfund Site was added to U.S. Environmental Protection Agency's (EPA's) National Priorities List (NPL) in 1987. The site is on the east side of Bainbridge Island, Washington, in the central Puget Sound. The Site encompasses the contaminated areas of Eagle Harbor and adjoining uplands of the former 57-acre Wyckoff wood-treating facility. The Wyckoff/Eagle Harbor Superfund Site made up of the following operable units:

- **East Harbor Operable Unit (OU-1):** The East Harbor OU includes subtidal and intertidal sediments of the outer harbor next to Wyckoff Point.
- **Soil Operable Unit (OU-2):** The Soil OU includes the former Wyckoff wood treating process and storage area.
- **West Harbor Operable Unit (OU-3)**: The West Harbor OU includes sediments and uplands of former shipyard.
- **Groundwater Operable Unit (OU-4):** The Groundwater OU includes the soil and groundwater in the saturated zone beneath the Soil OU.

From the early 1900s through 1988, a succession of companies treated wood at the Wyckoff property for use as railroad ties and trestles, telephone poles, pilings, docks, and piers. Initially, the poles were treated by wrapping with burlap and asphalt, but by 1910 pressure treatment began with creosote and/or bunker oil. Wood treatment operations involved using and storing creosote, pentachlorophenol, solvents, and petroleum products; generating process solid wastes and wastewater; and storing treated wood and other wood products. Operational features included storage tanks and process vessels, such as retorts, log peeler, and raw and treated log storage areas. Additional site history details are provided in various historical reference sources.

2.1 Previous Site Investigations and Remedial Actions

Numerous environmental investigation studies and several remedial actions have been conducted at the Wyckoff/Eagle Harbor Superfund Site since the 1980s. Key studies, activities, and other background information are listed and summarized in the Data Gaps Memo included as Appendix C to the Project QAPP (CH2M HILL 2012a). Separate remedial investigation (RI) and feasibility study (FS) investigations were also conducted for the Soil and Groundwater OUs associated with the upland portion of the former Wyckoff wood treatment facility. This work culminated with a sheet pile containment wall that was constructed between the upland OUs and intertidal area of OU-1 between 1999 and 2001. Several additional NAPL delineation and monitoring studies were conducted in intertidal and subtidal areas of OU-1 following installation of the sheet pile wall.

Between 1988 and 1993, several removal actions were conducted in the Soil and Groundwater OUs. Some of these removal actions extended to the current OU-1 FFS Project Area. In brief, buried sludge near the former West Dock, an underground pipeline and associated product and sludge located at North Shoal, and selected dock and pilings were removed during these removal actions (CH2M HILL 1994). Phase I capping was completed in 1994 over a substantial subtidal portion of the East Harbor. The Phase I cap extended toward the northwest portion of the FFS Project Area (Figure 1-1). Additional remedial actions were conducted between 1998 and 2003 for OU-1 within the FFS Project Area. From 1998 through 1999, many of the remaining in-water structures such as piers and pilings at the West Dock were removed. The sheet pile containment wall was installed between 1999 and 2001 around the northern and eastern portions of the Wyckoff upland facility, thereby inhibiting the potential for continued migration from upland sources. The sheet pile was driven into a glacial silt and clay aquitard at depths of up to about 90 feet below grade.

In 2001, a Phase II intertidal cap was completed that covered portions of North Shoal (Figure 1-1). A Phase III cap was completed in 2002 that including intertidal portions of the North Shoal and West Beach areas. The Phase III cap partially overlapped the Phase II cap. The Phase II and Phase III subtidal caps within the FFS Project area range in thickness up to approximately 12 feet and consist of quarry-run sand with “fish mix” gravel placed on top. An additional sand cover Exposure Barriers system was placed along the West Beach in 2007 and 2008. EPA’s Third 5-Year Review concluded that overall, the East Harbor remedy components are functioning as designed (EPA 2012). The 5-Year Review and other documents referenced in that report describe the performance objectives and implementation history of the various capping remedies and other actions.

2.2 2012 NAPL Investigation

CH2M HILL conducted the most recent field investigation at the Wyckoff OU-1 area in May, June, and July 2012 to better assess the three-dimensional extent of subsurface NAPL in the intertidal zone. The investigation and NAPL delineation results are detailed in the (final) Field Investigation Technical Memorandum (CH2M HILL 2013b). This field investigation built on results of NAPL product observations from previous site investigations to support the current OU-1 FFS. As a rapid field screening tool, the investigation utilized laser-induced fluorescence (LIF) via Tar-Specific Green Optical Screening Technology (TarGOST) developed by Dakota Technologies to detect the presence of polycyclic aromatic hydrocarbons indicative of NAPL derived from creosote. Visual NAPL observations and TarGOST data from the investigation were also evaluated in relation to sediment hydrostratigraphy. Findings from this investigation provided key information for the updated OU-1 CSM, and are described in detail in Section 3.

3. Site Characterization

This section discusses the current site conditions for the FFS Project Area including general site setting, sediment stratigraphy, hydrogeologic conditions, coastal environment, and NAPL distribution.

3.1 General Site Setting

The general marine setting of the FFS Project Area consists of beach and tideflat environments seaward of the sheet pile containment wall. Surface elevations within the FFS Project Area range from approximately 5 feet (mean lower low water [MLLW]) near the base of the vertical sheet pile wall to -2 feet MLLW to the seaward limit of the area. The beach face and tideflat comprise a low-angle landform with extensive shoaling areas reaching approximately 200 to 300 feet offshore. Intertidal sediments consist of variously bedded sands, gravels, and silts. Shoaling areas transition to deeper intertidal zones of the Puget Sound to the east of the FFS Project Area and to Eagle Harbor to the north and west. The intertidal environment supports eelgrass beds, other macroalgae, and shellfish. The extent of the eelgrass beds, as mapped by Washington State Department of Ecology (Ecology) during low tide on June 24, 2013 are further discussed with respect to their relationship to the FFS Project Area in Section 3.5. Generally, the eelgrass beds are offshore of NAPL product or sheen seeps observed during June 2013. The eelgrass beds are also offshore of the areas with the highest intensity TarGOST responses indicative of potential mobile NAPL. Shellfish and other ecological receptors are locally exposed to NAPL and associated chemical constituents in the FFS Project Area.

Although EPA’s policy is to discourage public beach use because of the presence of NAPL sheens and seeps representing potential exposure hazards, pet walking and other infrequent recreational activities are not uncommon. There are access points for non-motorized entry to the beach area on the southern portion of the

East Beach and from the West Beach. Vessel access is also possible. Potential exists for disturbance of near-surface sediments to typical depths of approximately 2 feet below grade based the recreational use scenario.

3.2 Site Sediments and General Stratigraphy

Sediment lithologies for the Site are divided into geologic units consistent with criteria developed by CH2M HILL during the Final Remedial Investigation (RI) Report for the Wyckoff Soil and Groundwater Operable Units (CH2M HILL 1997), and by the U.S. Army Corps of Engineers (USACE) for the Off-Shore Field Investigation Report for the Barrier Wall Design Project (EPA and USACE 1998). Geologic units and descriptions applicable to the OU-1 FFS Project Area are as follows:

- **Fill:** Brown, fine sand containing wood debris, anthropogenic debris, and infrequent shell fragments. Fill materials may be associated with historical shoreline development and modification activities.
- **Surficial Marine Sediment:** Dark olive, harbor bottom silt and clay, commonly with abundant wood chips and wood and plant debris.
- **Marine Silt:** Olive-gray silty sand with thin layers of and gravel, to silt or clay, and containing abundant shell fragments.
- **Marine Sand and Gravel:** Gray to dark gray, loose to dense sand and gravel with local cobbles, and low silt content and common shell fragments.
- **Marine Sand and Gravel (Gravel Zones):** Marine sand and gravel zones with dominant gravel and local cobbles, transitional into less coarse sediments.
- **Marine Sand:** Dark greenish gray to medium dark, dense to very dense sand with little silt or gravel. Zones of dominantly wood pulp and wood debris were also added as OU-1 units. These zones are characterized by dark gray/brown to black decomposing fibrous or pulpy wood.

The general occurrence and distribution of sediment types observed during the 2012 OU-1 investigation were consistent with the lithologies and geologic units identified in previous studies. The upper approximate 40 feet of the sediment profile (equivalent to elevations ranging from -25 to about -40 feet MLLW) are dominantly marine sand and gravel with coarser gravel zones and local cobbles. These units contain the sediment lithologies most commonly present in the FFS Project Area. Limited occurrences of the other units were noted during the 2012 field investigation and on exploration logs from older investigations. More detailed discussion of sediment lithologies is provided in the 2012 OU-1 Field Investigation Technical Memorandum (CH2M HILL 2013a), and will be further discussed in the FFS.

CH2M HILL evaluated occurrences of NAPL and based 2012 and historical sediment core data to assess NAPL distribution within the sediment units present in the OU-1 FFS Project Area. Review findings indicated a relatively complex distribution of NAPL with no strong spatial preference for particular geologic units. NAPL was most commonly observed in the marine sand and gravel unit and associated gravel zones. This is not unexpected, as these units are the most prevalent sediment lithologies in the area. NAPL was less commonly observed in each of the other geologic units. Similar conclusions apply to NAPL distribution indicated from TarGOST data, with no regular patterns of occurrence.

3.3 General Hydrogeologic Conditions

Limited data are available to define groundwater flow and gradient conditions in the FFS Project Area. The recently completed draft *Sheet Pile Wall – NAPL and Plume Migration Barrier Effectiveness Evaluation* (CH2M HILL, 2013c) supporting the Wyckoff upland feasibility study indicates that there is some is some hydraulic flux through the sheet pile wall via the seams; i.e. the wall is locally 'leaky'. A comparison of current to historical tidal efficiency factor measurements combined with the sheet pile wall construction information indicates that the current hydraulic flux between the upland and off-shore areas through the sheet pile wall is significantly less than during pre-wall conditions. NAPL observations within the channels welded to the sheet pile wall seams suggest that NAPL migration through the sheet pile wall seams is possible. As with the hydraulic flux, potential NAPL flux through the wall is expected to be localized.

Based on the reduction in upland hydraulic flux to off shore areas following installation of the sheet pile wall, groundwater within upper portions of the sediment profile beneath FFS Project Area is expected to be saline. In this environment, tidal forces represent the dominant dynamic force controlling groundwater flow, with cyclical horizontal and vertical gradients acting within the intertidal and shallow subtidal zone, i.e. between approximately elevations -10 to 12 feet MLLW depending on tide level. Review of a preliminary groundwater modeling conducted by CH2M HILL in 2004 (CH2M HILL 2004) indicates that net vertical gradients (steady state) are likely upward seaward of the sheet pile wall. However, groundwater elevation data have not been obtained from the OU-1 FFS Project Area to confirm gradient.

3.4 General Coastal Environment

The intertidal setting of the OU-1 FFS Project Area is influenced by wave action and tidal levels ranging from below about -3 feet to above 12 feet MLLW. Wakes from ferry travel and other vessels also affect the OU-1 coastal environment. As summarized as part of 2011 site monitoring activities completed by USACE, the mean diurnal tidal range in Eagle Harbor is 7.7 feet (USACE 2012). The tidal currents are weak in magnitude (less than 1 knot) and the North Shoal is fairly sheltered from wind generated waves because of the harbor geometry. USACE conducted elevation surveys and sediment mobility modeling including the OU-1 FFS Project Area as part of 2011 monitoring. Findings of the USACE work included the following:

- USACE concluded that the overall trend for intertidal areas of the North Shoal and East Beach is that both areas remain physically stable based on comparison of bathymetric data between 1999 and 2011. However, comparison of 2005 and 2011 bathymetry indicates apparent accretion of up to about 2 feet along upper intertidal portions of the northeastern part of the North Shoal and northern and central portions of the East Beach. USACE concluded that the overall trend was no net loss or gain of sediment for the North Shoal or East Beach since 1999. Localized areas of apparent erosion adjacent to the sheet pile wall show losses of less than about 1 foot of material and may be an artifact of the accuracy of the bathymetric survey.
- USACE evaluated potential for sediment transport from tidal currents, and wave-induced currents from wind-generated waves and vessel wakes. Maximum bed shear stresses from wind-generated waves were not found to exceed the critical shear stress for compromising the Eagle Harbor caps. Marginal exceedances of the critical shear stress from vessel wakes were noted that could potentially mobilize the finer fractions of sediments comprising the caps.

The USCAE sediment transport analysis did not extend to comparison with existing intertidal sediment grain size, but relatively coarse gravel to cobble-sized material on upper beach areas next to the sheet pile wall indicates relatively high wave energy has sorted these grain sizes in a state of dynamic equilibrium. Building on the USACE sediment transport analysis and mobility modeling, CH2M HILL conducted further coastal analysis modeling to effects of wave break and long-shore transport on sediment stability. These analyses and the associated results are presented in the CH2M HILL technical memorandum titled *Analysis of Wave-Driven Sediment Transport at the Wyckoff OU-1 Focused Feasibility Study Project Area, Bainbridge Island, Washington* (CH2M HILL 2013d). The key findings of this evaluation are as follows:

- The processes of wave transformation, breaking, and wave-driven current initiate mobilization of sediment from the seafloor bottom in the FFS Project Area vicinity. This mobilization can take place under weak or strong wave forcing, although entrained sediment concentrations are greater when larger waves are present.
- Wave-driven longshore current drives sediment transport northward along East Beach and follows the approximate shoreline curvature of the North Shoal. Longshore transport also carries material into the FFS Project Area from the south.
- Sediment transport investigated in this analysis originates from wave-induced currents and wave breaking processes. However, the USACE sediment mobility study found that tidal currents at the FFS Project Area are not sufficient to move material.
- Waves generated by winds from the south to southeast directions exert the dominant control on longshore currents and transport owing to stronger winds from southerly directions, greater fetch length, orientation of

the FFS Project Area relative to these directions, and exposure of the shoreline to waves arriving from the south and southeast. The FFS Project Area is relatively sheltered from waves arriving from the north and as a result, these waves have little effect on the FFS Project Area.

- Predicted rates of beach/seafloor morphology change at the FFS Project Area are relatively low even under 100-year extreme wind and wave forcing. Under normal conditions associated with more typical wind and wave conditions, morphology change is likely insignificant.
- Modeling results could be improved by calibration with higher resolution bathymetry. Because of uncertainty associated with modeling results based on the current bathymetry, some uncertainty is also associated with the rates of morphology change.
- Results do not indicate significant erosion in the FFS Project Area promoted by wave breaking.

3.5 NAPL Distribution in FFS Project Area Sediments

TarGOST response and sediment push probe sampling data from the 2012 OU-1 field investigation were compiled and evaluated to determine the inferred NAPL extent and association with sediment type. Data evaluation and presentation were aided by the use of a three-dimensional (3-D) visualization Mining Visualization Software (MVS) platform developed by C Tech Corporation of Henderson, Nevada. The MVS model allows integration of multiple OU-1 data sets including TarGOST results from Dakota Technologies, sediment lithology data, bathymetry, and historical information. The OU-1 investigation results were presented in the Field Investigation Technical Memorandum (CH2M HILL 2013b) as a series of MVS screen shots and section profiles figures derived from the MVS model.

3.5.1 Probabilistic Basis for NAPL Distribution

As presented in the Field Investigation Technical Memorandum, TarGOST data were statistically evaluated to develop a probabilistic interpretation of the likelihood of encountering NAPL at a given location based on TarGOST response. The probability approach was used as a means to address uncertainties inherent in depicting the distribution of NAPL using the TarGOST data set. Although the 2012 TarGOST data provides reasonable coverage over the FFS Project Area, it does not conform to a regular statistical distribution, leading to challenges in depicting kriging results in the most representative manner. The probability approach was applied to establish a further degree of statistical representation given the spatial variability of the TarGOST data set.

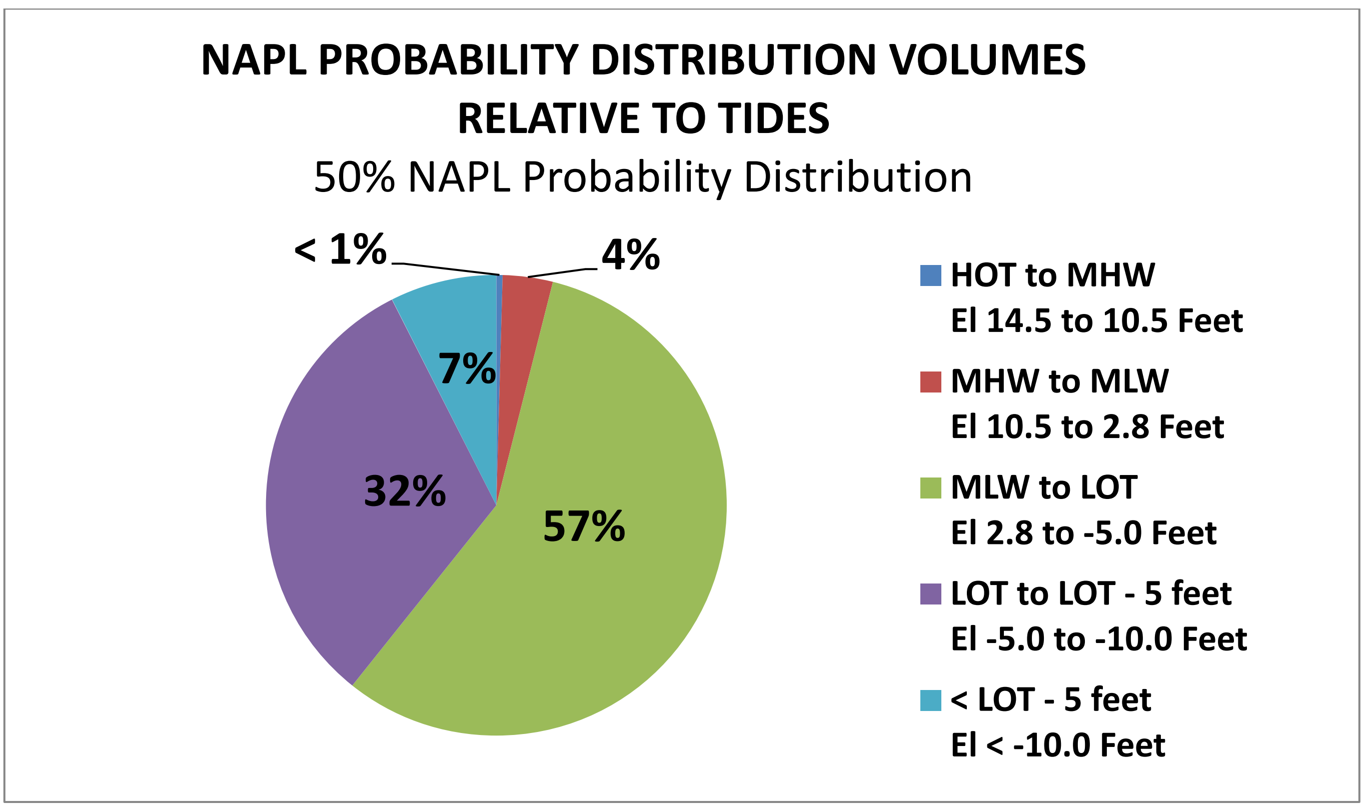
The overall approach for evaluating site TarGOST data, establishing variograms defining spatial variability, and completing the kriging analysis is based on methods described in Isaaks and Srivastava (1989). The application of these methods is further detailed in the Field Investigation Technical Memorandum. A standard kriging routine was applied based on the spatial distribution of TarGOST detections, as influenced by the proximity and persistence of neighboring detections. Statistical “experimental” variograms were constructed to develop 3-D fields where the likelihood of encountering NAPL is estimated for each TarGOST detection point at the 10, 50, and 90 percent levels. The kriged statistical results and probabilities must be cautiously interpreted because of the statistical uncertainties and graphical artifacts inherent in this approach. The probability distributions are intended as a useful guide for understanding the overall extent of NAPL distribution but should not be viewed as a definitive predictor.

NAPL Distribution

Figures 3-1, 3-2, and 3-3 are plan view depictions of the probability that NAPL would be present in the OU-1 FFS Project Area at levels of 90, 50, and 10 percent, respectively. The 90 percent probability level (Figure 3-1) represents the highest degree of certainty that NAPL would be present with a relatively low potential for non-detects. These areas are in the general vicinity or nearby known or suspected sources of historical contamination associated with the former Wyckoff wood treatment facility. Conversely, the 10 percent level (Figure 3-3) represents a relatively large volume over which NAPL could be present, but with a higher degree of uncertainty and potential for TarGOST non-detects. The 50 percent probability is an intermediate case depicting a moderate degree of lateral continuity or statistical reach from kriging. In applying the probability distributions it should be noted that the probability estimates are based only on NAPL statistical distributions and do not account for porosity or NAPL saturation. These estimates therefore do not represent the actual volume of NAPL product present, only the statistical distributions of whether NAPL is present. This statistical approach also does not imply that NAPL is necessarily continuously present within the areas and volumes shown, or is contiguous between TarGOST detection locations.

The 2012 TarGOST field investigation results were further evaluated using 3-D MVS modeling to determine volumetric NAPL probability distributions relative to various elevation ranges and tidal zones. Figures 3-4 and 3-5 are oblique view MVS model screen shots presenting 3-D NAPL extent based on the 50 percent probability distribution, i.e. corresponding to the Figure 3-2 plan view depiction of the 50 percent distribution. Various depth intervals are color-coded based on tidal datum references for lowest and highest observable tide (LOT and HOT), and mean high and low water (MHW and MLW). These tidal references provide a basis for comparing the estimated 50% NAPL probability distribution with respect to various tidal hydraulic influences. A compendium MVS "4DIM" viewing file is provided with this CSM Technical Memorandum to facilitate additional manipulation of the 3-D spatial model at higher resolution.

Representative cross sections are presented for the North Shoal and East Beach on Figures 3-6 and 3-7, respectively for the 50% NAPL probability distribution. In addition, Table 3-1 presents the estimated percent distribution of NAPL probability occurrences between various tidal elevation intervals. Review of Figures 3-6 and 3-7 and Table 3-1 indicates that probability of encountering NAPL is highest between the lowest observed tide elevation (LOT) of –5.0 feet MLLW and the mean low water elevation (MLW) of 2.8 feet MLLW. This elevation range between LOT and MLW contains 81 percent of estimated distribution volume at the 10 percent probability distribution level, 89 percent for the 50 percent probability distribution level, and 91 percent for the 90 percent probability level. Less than 7 to 13 percent of the NAPL distribution occurs below LOT and less than 2 to 5 percent occurs above MLW. A pie chart of relative distribution for the 50 percent probability distribution is presented below. These conclusions represent key findings describing the likely extent of NAPL for the CSM.



3.5.2 NAPL Saturation and TarGOST Response Level

The 2012 field investigation identified the presence or absence of NAPL at various locations based on detections above the TarGOST method threshold response criterion. This threshold response criterion was defined as 10 percent of the reference material emitter (RE) response (10%RE), as detailed in the 2012 Field Investigation Technical Memorandum (CH2M HILL 2013b). The 10%RE response level represents the threshold above which TarGOST readings are interpreted as actual NAPL detections. TarGOST readings below this level are considered background and not definitively indicative of NAPL presence. The 10%RE criterion was selected to balance potential false negatives above this threshold with false positives below due to background interference. Reference material response was documented at the beginning of each TarGOST probe run as a standard calibration procedure.

TarGOST detections above the 10%RE threshold response criterion were counted as "hits" without attempting to determine the degree of NAPL saturation in relation to the TarGOST response level. Determination of NAPL condition in the sediment pores indicated by TarGOST responses above some critical level requires comparison of TarGOST data with additional NAPL properties testing such as NAPL density, viscosity, interfacial surface tension, sediment grain size, and pore fluid saturation. Although NAPL properties testing was not completed for OU-1 FFS, TarGOST readings of greater intensity above some critical RE response level (not currently defined) are likely indicative of mobile or residual NAPL conditions. Relatively high intensity TarGOST readings hundreds of times greater than the RE response likely indicate high pore fluid saturation NAPL conditions and potentially mobile NAPL. Conversely, relatively low intensity readings just above the 10%RE threshold are unlikely to indicate the presence of potentially mobile NAPL where the NAPL is in a residual condition.

To further evaluate the NAPL saturation issue for the CSM and FFS, TarGOST results above a nominal and somewhat arbitrary 50%RE response cutoff are presented on Figure 3-8. This figure presents information to illustrate:

- TarGOST readings above the nominal 50%RE cutoff, of which all or a subset could indicate mobile NAPL absent supporting NAPL properties data.
- Additional uncertainty associated with the variability of responses above 50%RE in terms of standard deviation to identify potential spatial data gaps in TarGOST coverage.
- Locations of seeps observed by CH2M HILL and Ecology during a June 24, 2013 site visit.
- Extent of the eelgrass identified by Ecology during the June 24, 2013 site visit.

The colored area "flooding" projected onto the "isosurface" of greater than 50%RE presented on Figure 3-8 represents one standard deviation. The standard deviation halos include locations with greater certainty of the TarGOST response (plus or minus 2%RE) to areas of less certainty (plus or minus 21%RE). These standard deviations are an output of the variogram used for kriging. TarGOST detections at many of the East Beach locations exhibit a higher degree of certainty because of the proximity of nearest neighbors that constrain spatial variability. Several North Beach locations including 43, 44, and 132 exhibit greater uncertainty because of the absence of closer nearest neighbors. A compendium MVS 4DIM viewing file is provided with this CSM Technical Memorandum to facilitate additional manipulation of the 3-D spatial model of the 50%RE isosurface at higher resolution.

These concepts are useful for defining remedial target areas in the FFS with the highest potential for NAPL saturation. Locations with higher standard deviations also define areas of greater spatial uncertainty as potential data gaps. Although the selection of different %RE cutoffs would result in a different distribution of detections and standard deviations, Figure 3-8 provides a useful evaluation tool to support development and comparison of remedial alternatives in the FFS.

Figure 3-8 also illustrates the present extent of the eelgrass beds in context of the TarGOST 50% response data. The TarGOST detections with the highest degree of certainty are almost all in-shore of the eelgrass beds. The exceptions to this observation are at TarGOST location 33, on the East Beach, and location 44, which is on the North Shoal. CH2M HILL observed four NAPL seeps on June 24, 2013; three of the observed seeps were coincident with locations exhibiting relatively high-intensity TarGOST results and were inshore of the eelgrass bed.

The fourth location was observed approximately 225 feet from the sheet pile wall, offshore of TarGOST locations 107 and 108 on the East Beach. This seep is within an eelgrass bed identified by Ecology on June 24, 2013, but is outside of the OU1 boundary. Ecology staff reported that they observed eight seeps during the June 24 site visit, five near the OU1 boundary and within eelgrass beds on the North Shoal, one nearer to the sheet pile wall on the North Shoal, and two on the East Beach. The seeps observed by Ecology on the East Beach were not within the eelgrass bed.

4. Revised Conceptual Site Model

This section provides a framework for understanding site-specific features and physical processes that influence the potential exposure pathways for NAPL within the OU-1 FFS Project Area. The development of the revised CSM is a dynamic process based on currently available site information, estimated extent of NAPL, and the FFS exposure scenarios for direct contact of recreational beach users. This revised CSM will be used as the basis for developing and evaluating remedial alternatives in the OU-1 FFS.

4.1 NAPL Transport Processes

The theory and equations describing NAPL fate and transport in saturated sediment are developed based on the EPA *DNAPL Site Evaluation* document (EPA 1993). As described in this document, subsurface dense NAPL (DNAPL) in the saturated zone is acted upon by three forces:

- **Gravity**. The buoyancy difference between the water and DNAPL creates a downward force for DNAPL migration.
- **Capillary pressure**. The capillary pressure holding the wetting fluid (water) within soil or sediment pore spaces must be overcome for non-wetting fluid DNAPL migration to occur.
- **Hydrodynamic pressure**. Groundwater movement through DNAPL zones creates a hydrodynamic force that, while commonly minor compared to the force of gravity or capillary pressure, can influence the migration of DNAPL.

The same forces affect light NAPL (LNAPL) migration with the following modifications:

- **Gravity**. The buoyancy difference between the water and LNAPL creates an upward force for LNAPL migration through saturated media.
- **Capillary Pressures**. LNAPL rests on top of the water table resulting in a three-phase system (air, water, and LNAPL) where LNAPL is present. Changes in capillary pressure gradients are the primary mechanism for lateral LNAPL migration (American Petroleum Institute 2007).
- **Hydrodynamic pressure**. Forces associated with water or air movement contribute to LNAPL migration. The force from air movement is typically negligible.

Neutrally buoyant NAPL may also persist within the OU-1 Project Area and is affected by the same forces:

- **Gravity**. There is no buoyancy difference between the water and NAPL creates, which eliminates gravity as a force for migration.
- **Capillary pressure**. The capillary pressure holding the wetting fluid (water) within soil or sediment pore spaces must be overcome for non-wetting fluid NAPL migration to occur.
- **Hydrodynamic pressure**. Groundwater movement through neutrally buoyant NAPL zones creates a hydrodynamic force that, while commonly minor compared to the force of gravity or capillary pressure, can influence the migration of NAPL.

The presence of neutrally buoyant NAPL and the OU-1 FFS Project Area's intertidal environment adds complexity because of tidal effects, wave action, and interaction of NAPL with saltwater. Because saltwater has a greater density than freshwater, freshwater discharge from the upland has the potential to affect gravitational forces on neutrally buoyant NAPL and DNAPL. These forces and mechanisms for NAPL migration are used to develop this revised CSM focusing on NAPL migration.

4.2 NAPL Characteristics

Physical and chemical characteristics and properties of resident NAPL from the Wyckoff OU-1 FFS Project Area are not available. Attempts to collect NAPL product samples for TarGOST calibration were unsuccessful during the 2012 field investigation because of insufficient sample volume and unavoidable product dilution with near-surface water in the intertidal zone. Alternatively, LNAPL product samples from upland wells were collected for TarGOST calibration as described in the Field Investigation Report. This provided the best available NAPL product material for the calibration purposes during the 2012 OU-1 TarGOST exploration work.

In addition, historical upland NAPL properties data are available from the USACE 1999 pre-remedial design field exploration for the Wyckoff/Eagle Harbor Superfund Site (USACE 2000). Available data include upland NAPL product chemical composition, density, oil-water interfacial tension, and solubility measurements. Because the 1999 NAPL samples were collected from upland site wells with accumulated NAPL, these samples represent mobile phase product. These samples provide comparative information for assessing properties of Wyckoff NAPL originating from upland sources, although NAPL properties may change with subsurface transport to the intertidal area. Changes to NAPL properties can occur through potential chromatographic-like separation, geochemical interaction with substrate, and constituent weathering. As a result, the NAPL samples collected from upland extraction wells may not fully represent the characteristics of NAPL present in the OU-1 intertidal area.

Table 4-1 presents the chemical composition of historical upland NAPL samples collected as part of the USACE 2000 field exploration activities. NAPL composition results are available for seven upland wells, with analyzed constituents including benzene, toluene, ethylbenzene, and xylenes (BTEX), low and high molecular weight polycyclic aromatic hydrocarbons (LPAHs and HPAHs), and pentachlorophenol (PCP). Two of the samples represent LNAPL with the remaining representing DNAPL. This data set was evaluated using the EPA Fingerprint Analysis of Leachate Contaminants (FALCON) analysis (EPA 2004) to identify the chemical signature of the NAPL samples. Figure 4-1 presents the graphical fingerprints of the PAH and PCP constituents for individual samples. The NAPL samples contained comparable proportions of naphthalene and other LPAHs including acenaphthene, fluorene, phenanthrene, and anthracene. Pyrene and fluoranthene were the most prominent HPAHs detected. PCP was detected in several samples but was a minor component compared to the LPAH and HPAH constituents. The chemical fingerprints of NAPL samples presented on Figure 4-1 exhibit limited variability and establish a consistent compositional pattern of PAHs.

For the NAPL samples collected from the upland wells, Table 4-2a and 4-2b present density measurements of both NAPL and groundwater, Table 4-3 presents the interfacial tension measurements, and Table 4-4 presents the viscosity measurements. All measurements in Tables 4-2 through 4-4 are presented as a function of temperature. The density measurements can be used to estimate density gradients relative to freshwater and saltwater. The interfacial tension measurements can be used to estimate surface tension and the spreading coefficient to evaluate potential sheening. Viscosity measurements can be used to evaluate the potential flux rate based on assumptions regarding hydraulic and density gradients, along with the relative conductivity of NAPL. These are discussed further below.

A 2001 investigation conducted by Battelle indicated that the fingerprint of total petroleum hydrocarbons (TPH) in Wyckoff sediment samples was characterized as consisting of various two-ring LPAHs (i.e. Carbon [C] 0 to C4 naphthalenes) and three- and four-ring LPAH and HPAH compounds (phenanthrene, anthracene, fluoranthene, and pyrene). No significant petroleum-derived components or contributions from plant waxes were identified. This investigation concluded the characteristics of TPH in the Wyckoff sediment samples are typical of various coal-derived liquid products formed during the heating/conversion of coal, most consistent with creosote. (Battelle 2001)

4.3 NAPL Fate and Transport

This section focuses on the aspects of the revised CSM related to resident NAPL sources in intertidal sediments and NAPL fate and transport processes. The revised CSM describes effects of creosote releases under:

- Conditions prior to implementation previous remedial actions to control upland sources including installation of the sheet pile wall between 1999 to 2001, and

- Current conditions influenced by installation of the sheet pile wall and implementation of other remedial actions.

4.3.1 Conditions Prior to Remedial Actions

Figure 4-2 presents the NAPL conceptual site model under historical conditions prior to implementing remedial actions at the Wyckoff site. The features on the left side figure block illustrate the following:

- Releases of NAPL from upland operations migrated downward through the vadose zone into the saturated zone of the upper aquifer located within fill and marine sediments comprising upland soils.
- NAPL separated into LNAPL, neutrally buoyant, and DNAPL phases. LNAPL is defined in this CSM as having a specific gravity less than water. Neutrally buoyant NAPL is defined as NAPL with specific gravity equal to water, i.e. gravity forces are insufficient to promote downward migration of NAPL toward the aquitard. This can also be caused by hydraulic gradients that push NAPL upward and/or where the capillary pressures of underlying sediments are greater than the gravity forces. NAPL reaching the upper aquifer migrated laterally along the top of the water table as an LNAPL, laterally within groundwater as neutrally buoyant NAPL, and downward by gravity as DNAPL.
- NAPL that migrated downward to the low permeability aquitard layer migrated along the stratigraphic gradient.
- NAPL released directly to the intertidal area have also been documented. These releases would migrate by the same saturated zone transport mechanisms as described.

The right-side figure block illustrates the conditions of freshwater discharge to saltwater during the tidal cycle, as well as conceptual NAPL migration and seep discharge. The conceptualized tidal exchange cycle was adapted from “Tidal Effects on Ground Water Discharge Through a Sandy Marine Beach” (Urish and McKenna 2004). This tidal exchange cycle includes flow patterns through four stages of groundwater discharge and seawater infiltration:

- At high tide (upper left graphic), groundwater discharge is suspended and hydraulic gradient is influenced by inundation of the shallow subsurface with tidal waters. Saltwater infiltrates into beach sediments, generally overriding and mixing with shallow fresh groundwater.
- During the ebb tide (upper right graphic), the hydraulic gradient reverses and groundwater flow moves seaward as discharge begins. Tidal seeps from bank storage water begin to appear.
- During low tide (lower right graphic), groundwater discharge continues, both as discharge from the exposed beach face and as subaqueous discharge to marine surface water at lower elevations.
- During the flood tide (lower left graphic), gradient again reverses under with influence of the incoming tide and groundwater discharge ceases.

NAPL migration and seep discharge depict LNAPL and neutrally buoyant NAPL migration driven by strong upland NAPL gradients, with a NAPL pressure head potentially as high as the original source elevation. The potential presence of DNAPL associated with the deep aquitard surface is unknown, although TarGOST results from the 2012 OU-1 FFS field investigation did not indicate prevalent NAPL zones below about 20 to 25 feet depth. This suggests that deeper DNAPL, if present, has limited if any potential for vertical migration and communication with shallower NAPL zones in the OU-1 FFS Project Area. Conversely, the TarGOST data suggest little if any downward migration of the shallower NAPL zones encountered.

4.3.2 Conditions Following Remedial Actions (Current Conditions)

Figure 4-3 presents the NAPL conceptual site model under current conditions following implementation of upland remedial actions at the Wyckoff site

Seep Migration

A NAPL seep is defined as a NAPL discharge where:

- NAPL saturations are above residual and a NAPL wetted pathway exists, or where NAPL can move under a sustained gradient and overcome the capillary forces of water-wetted sediment.
- A NAPL gradient provides the driving force for NAPL discharge at seep areas.
- A recent or ongoing NAPL release is typically associated with seep discharges.

NAPL seeps can more readily migrate through sediments previously impacted with NAPL where NAPL is the wetting fluid (Cohen and Mercer 1993). Once established, wetted pathways can become sustained conduits for continued migration of NAPL from source to seep. When NAPL is non-wetting and water is the wetting phase, NAPL migrates when the NAPL head exceeds the pore entry capillary pressure of the groundwater and displaces the water to become the new wetting phase. This allows NAPL to migrate to areas previously unaffected by NAPL. When NAPL is the wetting fluid, NAPL discharge is likely continuous since the driving head of NAPL continues to release NAPL along the NAPL-wetted pathway. In addition historical seep migration can create NAPL wetted sediments where NAPL is the wetting fluid. NAPL wetted sediments can then provide a preferential pathway for migration because the capillary forces to inhibit migration are no longer present.

Based on the information presented above, NAPL seep migration was likely an active NAPL transport pathway in the past for the intertidal area and is considered a potentially active transport mechanism currently. Possible NAPL wetted pathways from past NAPL seeps can also be conduits for NAPL migration by other mechanisms such as sheen migration. Localized NAPL seeps identified by CH2M HILL during the June 24, 2013 site are identified on Figure 3-8 and consisted of small blebs that quickly dissipated upon contact with surface water.

Sheen Migration

NAPL sheen is defined as a NAPL discharge where:

- A relatively limited amount of product is discharged as sheen on the water surface.
- Ephemeral sheen behavior may be observed.
- Former seep areas may be present.
- NAPL saturations are close to or below residual.

NAPL sheens migrate by the difference in the surface tensions that result in the spreading of NAPL on the water surface (Sale 2011). In subsurface sediments, NAPL spreads on the groundwater surface in the same manner as sheening on exposed surface water. NAPL sheen spontaneously enters water-coated, air-filled pores through capillary forces in this manner. Interfacial tension measurements from NAPL samples collected from upland extraction wells indicate a positive spreading coefficient, consequently spontaneous sheening is predicted to occur as NAPL moves from an oil-water system (two-phase) to an oil/water/air system (three-phase). This condition would be expected in the OU-1 intertidal area for NAPL migrating from tidal exchange through the tide cycle. Once formed, sheen can then migrate laterally along water table and discharge where the water table intersects with surface water. With each tidal cycle, sheen migration has the potential to continue to create NAPL discharges.

Based on the information presented above, NAPL sheen migration is considered an active NAPL transport mechanism for the intertidal area.

NAPL Migration with Groundwater Advection and Buoyancy

When the hydrodynamic force from upward moving groundwater exceeds the gravity and capillary force of the NAPL, upward migration of NAPL can occur. For conditions where the NAPL specific gravity is near that of the seawater, a smaller upward gradient is needed for NAPL migration. Two-dimensional groundwater modeling performed when the sheet pile wall was installed indicated a steady state upward hydraulic gradient from the deeper aquitard into the upper aquifer of intertidal zone (CH2M HILL 2004). The predicted upward hydraulic gradient, shown on the left side block of Figure 4-3, may promote a sufficient upward hydraulic gradient to mobilize NAPL toward the active tidal zone

The intertidal area is also subject to transient groundwater gradients during the tidal exchange cycle. Generalized numerical simulations of tide-induced seawater-groundwater circulation in shallow beach aquifers, presented by Li et al. (2008), demonstrate that the maximum Darcy velocity occurs at the intersection of the water table and the beach surface, and that offshore beach groundwater is almost stagnant compared with onshore groundwater flow. This tidal exchange cycle results in continuous and intense flushing of the horizontal plane between high and low tide.

The installation of the sheet pile wall blocked large-scale discharge of upland groundwater from the upper aquifer to the intertidal area, thereby altering the dynamics of groundwater discharge and seawater infiltration. The sheet pile wall effectiveness evaluation completed by CH2M HILL (2013c) indicated localized hydraulic flux and NAPL presence in the sheet seam channels, but these conditions would not substantially affect the intertidal hydraulic regime or create significant NAPL conduits. Consequently, seawater is now expected to infiltrate up to the sheet pile wall. Because upland groundwater has a lower density than seawater, a larger buoyancy force exists for upward NAPL migration following construction of the sheet pile wall.

Based on the information presented above, NAPL migration with groundwater advection and density gradients is considered an active NAPL transport mechanism for the intertidal area.

Ebullition

Ebullition is the production of gas due to anaerobic biological activity in sediment (Viana et al. 2007a). Mineralization of organic matter by bacteria in the sediment generates gases such as methane, nitrogen, carbon dioxide, and other gases (Reible 2004). Gas ebullition acts as a NAPL transport mechanism. The bubbles produced during ebullition tend to accumulate hydrophobic contaminants and colloids, such as NAPL sheen, on their surfaces (Viana et al. 2007b). This NAPL can then travel out of the sediment and be deposited on the water surface as a sheen while the gas bubbles migrate upwards through the water column.

The degree ebullition affects NAPL migration in the intertidal area of the Wyckoff site is unknown. Given the dynamic exchange of seawater during the tidal cycle, evidence of ebullition may be difficult to observe. NAPL migration through ebullition is a possible NAPL transport mechanism for the intertidal area, but may be minor in comparison with other potential migration pathways.

Effect of Sheet Pile Wall

The sheet pile wall completed in 2002 provides a substantial physical and hydraulic barrier between the upland area of the Wyckoff site and OU-1 intertidal area. The sheet pile wall acts as a restrictive barrier to large-scale hydraulic flux and NAPL migration from upland sources to the intertidal areas. The presence of NAPL observed in the sheet pile wall seam channels suggests that localize NAPL migration through the seams is possible on a small scale. Upland NAPL migration may therefore be a potential pathway for NAPL discharge in the intertidal area on a limited scale, but is not anticipated to substantially alter the current NAPL distribution or quantity. Based on these observations, NAPL remaining in the subsurface within the OU-1 intertidal zone is dominantly resident product that migrated from the upland prior to sheet pile wall installation, and is now hydraulically controlled by tidal and buoyancy influences.

4.4 NAPL Conceptual Site Model Summary

The following pathways are considered the active NAPL transport mechanisms for NAPL affecting the beach surface at the Wyckoff OU-1 FFS Project Area:

- **Seep Migration.** Historical NAPL product seeps were noted at many locations in previous investigations including field studies prior to installation of the sheet pile wall. Observations of NAPL product diminished following sheet pile wall installation. The most recent OU-1 field studies conducted in 2011 by USACE (2012) and in 2012 by CH2M HILL (2013b) identified limited occurrences of near-surface product observed in shallow core samples and hand-dug holes. No actual product seeps on the beach face were noted. Product occurrences included six central East Beach locations between about elevations 1 to 2 feet MLLW. Product observed in 2012 included small NAPL blebs several millimeters in size in shallow hand-dug holes that quickly filled with surface water. In addition, TarGOST readings of up to about 250%RE were noted at depths of less than 2 feet at five East Beach locations and two North Shoal locations. TarGOST readings of this magnitude may represent shallow zones of NAPL with likely mobility. This weight of evidence indicates that active seep migration may still be occurring to the beach face, although pure product blebs appear to quickly dilute upon contact with surface water and beach exposure.

- **Sheen Migration.** The tidal cycle allows transient contact with the flood tide in NAPL impact areas. As NAPL contacts groundwater, it produces a sheen that can migrate along the water-air interface and discharge to surface water. During 2012 low tide field visits, CH2M HILL observed NAPL sheen conditions at locations along the East Beach and North Shoal between about 0 and 2 feet elevation MLLW. The prevalence and intensity of sheening varied with tidal stage. Sheening was typically most pronounced as the outgoing tide exposed sheen areas at the elevations noted, then dissipated somewhat as discharge from tidal bank storage diminished. Tidal flux is expected to be the primary factor controlling the presence and dynamics of intertidal sheening. This transport mechanism is active at elevations between low and high tide where an air-water interface is present.
- **Groundwater Advection and NAPL Buoyancy.** There is a steady state upward hydraulic gradient in the intertidal area. This coupled with the increased groundwater density because of elimination of freshwater discharge from upland groundwater, has the potential to alter the density gradient and move the NAPL upward. In many locations, sediment is likely NAPL wetted from previous head-driven NAPL seeps from the upland. NAPL wetted sediment have low (or zero) capillary barrier to overcome for upward migration.

Tidal exchange plays an important role in controlling the distribution of NAPL within the intertidal area. Because the intertidal area is subject to transient groundwater gradients, and the maximum Darcy velocity occurs at the intersection of the water table and the beach surface, the tidal exchange cycle results in continuous and intense flushing of the horizontal plane between high and low tide. Because of this phenomenon, NAPL that is resident within the active tidal zone or migrates to this horizon from below is subject to release into the beach environment from the mechanisms described above.

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TABLE 3-1. SUMMARY OF NAPL PROBABILITY DISTRIBUTION VOLUMES RELATIVE TO TIDES

Wyckoff OU-1 Preliminary Revised Conceptual Site Model Technical Memorandum

Tidal Interval	Elevation Range in Feet (MLLW)	Units	90% NAPL Probability Distribution	50% NAPL Probability Distribution	10% NAPL Probability Distribution
> HOT	> 14.5	cubic feet	0	0	20
HOT to MHW	14.5 to 10.5	cubic feet	26	1,947	15,936
MHW to MLW	10.5 to 2.8	cubic feet	1,316	15,605	73,491
MLW to LOT	2.8 to -5.0	cubic feet	50,190	253,058	899,123
LOT to LOT - 5 feet	-5.0 to -10.0	cubic feet	25,786	141,680	455,530
< LOT - 5 feet	< -10.0	cubic feet	5,809	33,270	217,400
Total Estimated Volume	**< -10.0 to >14.5**	**cubic feet**	**83,127**	**445,560**	**1,661,500**
> HOT	> 14.5	percent	0%	0%	0.001%
HOT to MHW	14.5 to 10.5	percent	0.03%	0.4%	1%
MHW to MLW	10.5 to 2.8	percent	2%	4%	4%
MLW to LOT	2.8 to -5.0	percent	60%	57%	54%
LOT to LOT - 5 feet	-5.0 to -10.0	percent	31%	32%	27%
< LOT to 5 feet	< -10.0	percent	7%	7%	13%
			100.0%	100.0%	100.0%

Notes:

HOT	Highest Observed Tide elevation: 14.5 feet MLLW between 1983 and 2001
LOT	Lowest Observed Tide elevation: -5.0 feet MLLW between 1983 and 2001
MHW	Mean High Water elevation: 10.5 feet MLLW
MLW	Mean Low Water elevation: 2.8 feet MLLW
MLLW	Mean Lower Low Water elevation: 0 feet

Table entries represent statistical distribution volumes with no adjustment made for porosity or NAPL saturation.

The volumes do not reflect actual NAPL product volume.

TABLE 4-1. EPA FINGERPRINT ANALYSIS OF LEACHATE CONTAMINANTS (FALCON) FOR WYCKOFF SUPERFUND SITE HISTORICAL UPLAND SAMPLES

Wyckoff OU-1 Preliminary Revised Conceptual Site Model Technical Memorandum

Compound / Sample Name:	PW3 LNAPL	PW4 LNAPL	PW5 DNAPL	PW6 DNAPL	PW6 LNAPL	PW8 DNAPL	PW9 DNAPL	Average	Mass fraction (%)
Toluene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000
Ethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000
m,p-Xylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000
o-Xylene	0.0	2.2	0.0	0.0	0.0	0.0	2.4	0.65	0.065
Phenol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000
Naphthalene	305.7	335.3	400.6	376.3	298.0	333.7	385.7	347.9	34.790
2-Methylnaphthalene	148.1	166.9	74.9	70.7	135.8	128.2	156.4	125.9	12.587
Acenaphthylene	2.2	2.3	2.4	2.3	2.3	2.3	2.3	2.3	0.231
Acenaphthene	24.8	22.0	31.0	30.1	20.6	29.0	31.1	26.9	2.694
Dibenzofuran	13.4	10.7	23.0	24.4	10.7	20.5	26.1	18.4	1.841
Fluorene	12.4	9.4	25.7	27.6	10.0	22.1	25.6	19.0	1.896
Pentachlorophenol	2.4	0.0	2.5	0.0	2.4	2.4	0.0	1.4	0.138
Phenanthrene	25.7	19.4	61.8	0.0	20.7	27.6	63.7	31.3	3.128
Anthracene	4.1	4.0	6.8	7.0	4.2	5.9	8.2	5.8	0.575
Carbazole	0.0	0.0	4.9	4.7	2.7	4.2	6.6	3.3	0.329
Fluoranthene	12.0	8.1	26.9	26.4	9.1	23.7	21.7	18.3	1.828
Pyrene	7.1	5.1	14.8	14.3	5.6	13.0	11.3	10.2	1.016
Benz(a)anthracene	2.6	2.3	4.1	3.7	2.4	3.9	2.9	3.1	0.314
Chrysene	2.6	2.4	3.8	3.5	2.5	3.6	2.8	3.0	0.303
Benzo(b)fluranthene	2.4	2.3	2.8	2.6	2.4	2.7	2.4	2.5	0.250
Benzo(k)fluoranthene	2.3	2.2	2.6	2.4	2.3	2.5	2.3	2.4	0.238
Benzo(a)pyrene	2.4	2.3	2.7	2.5	2.4	2.6	2.4	2.5	0.246
Indeno(1,2,3-cd)pyrene	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.3	0.032
Dibenzo(a,h)anthracene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000
Benzo(g,h,i)perylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000
Sum	570	597	691	599	534	630	754	625	62.501
Total PAH	568	595	684	594	529	624	745	620	125.001
non-PAH	432	405	316	406	471	376	255	380	37.499

Notes:

Upland NAPL samples were collected as part of the USACE 2000 field exploration activities (USACE, 2000).

This data set was evaluated using the EPA Fingerprint Analysis of Leachate Contaminants (FALCON, EPA 2004) analysis to identify the chemical signature of the NAPL samples.

TABLE 4-2A. WYCKOFF CREOSOTE DENSITY (GM/ML) AS A FUNCTION OF TEMPERATURE

Wyckoff OU-1 Preliminary Revised Conceptual Site Model Technical Memorandum

		Creosote Density (gm/ml) for Given Temperature			
Sample	**Location**	**10 °C**	**20 °C**	**30 °C**	**40 °C**
9929352 P001 DNAPL Average density	P001	1.027	1.019	1.013	1.006
9929365-1 RPW-1 DNAPL Average density	RPW-1	1.052	**1.046**	1.037	1.030
9929365-2 RPW-3 DNAPL Average density	RPW-3	1.024	1.017	1.009	1.003
9929365-3 RPW-6 DNAPL Average density	RPW-6	1.045	**1.036**	1.028	1.022
9929365-4 RPW-5 DNAPL Average density	RPW-5	1.036	**1.028**	1.026	1.012
9929365-6 RPW-8 DNAPL Average density	RPW-8	1.029	1.021	1.013	1.007
9929365-7 RPW-9 DNAPL Average density	RPW-9	1.044	**1.037**	1.030	1.021
9929365-0 RPW-1 LNAPL Average density	RPW-1	1.008	1.003	0.999	0.994
9929365-5 RPW-3 LNAPL Average density	RPW-3	1.005	1	0.994	0.988
9929365-8 RPW-4 LNAPL Average density	RPW-4	0.981	0.973	0.965	0.956
9929365-9 RPW-6 LNAPL Average density	RPW-6	0.978	0.971	0.963	0.955
NAPL Statistics	min	0.978	0.971	0.963	0.955
	max	1.052	1.046	1.037	1.03
	average	1.021	1.014	1.007	0.999
	stdv	0.025	0.025	0.025	0.025
	count	11	11	11	11
LNAPL Statistics	min	0.978	0.971	0.963	0.955
	max	1.005	1.003	0.999	0.994
	average	0.988	0.987	0.980	0.973
	stdv	0.015	0.017	0.019	0.021
	count	3	4	4	4
DNAPL Statistics	min	1.008	1.017	1.009	1.003
	max	1.052	1.046	1.037	1.03
	average	1.033	1.029	1.022	1.014
	stdv	0.014	0.011	0.011	0.010
	count	8	7	7	7
GW Statistics	min	0.999	0.996	0.993	0.99
	max	1.020	1.017	1.014	1.010
	Average	1.006	1.004	1.001	0.998
	Standard deviation	0.007	0.007	0.007	0.007
Comparison	Percent LNAPL	27%	36%	36%	36%
	LNAPL density gradient	-0.018	-0.017	-0.020	-0.024
	Percent DNAPL	73%	64%	64%	64%
	DNAPL density gradient	0.027	0.025	0.022	0.017
	Percent <Saltwater density		64%		
	Associated density gradient of average LNAPL		-0.037		
	Percent >Saltwater Density		36%		
	Associated density gradient of average DNAPL		0.004		

Notes:

This table is adapted from Table 5 from the *Wyckoff Steam Injection Treatability Study* (Davis 2002).

1.008 or greater Shaded formatting denotes DNAPL

1.044 or greater Shaded and bold formatting denotes NAPL > than salt water density

The density of seawater is approximately 1.025 grams per cubic centimeter at a salinity of 35‰ and 20° C (Lamb 2003-2004).

density gradient = (density of NAPL - density of water)/density of water

gm/ml = gram per milliliter

TABLE 4-2B. WYCKOFF GROUNDWATER DENSITY (GM/ML) AS A FUNCTION OF TEMPERATURE

Wyckoff OU-1 Preliminary Revised Conceptual Site Model Technical Memorandum

	Groundwater Density (gm/ml) for Given Temperature			
Location	**10 °C**	**20 °C**	**30 °C**	**40 °C**
EWC3	1	0.997	0.995	0.99
EW7	1.007	1.005	1.002	0.999
EW7	1.014	1.012	1.008	1.005
MW14	1.02	1.017	1.014	1.01
PO3	1.006	1.003	1.001	0.997
PO9	1.003	1	0.996	0.994
PO11	0.999	0.996	0.993	0.993
PO17	1.001	0.996	0.993	0.99
EW03	1.008	1.006	1.004	1
min	0.999	0.996	0.993	0.990
max	1.020	1.017	1.014	1.010
Average	1.006	1.004	1.001	0.998
Standard deviation	0.007	0.007	0.007	0.007

Notes:

This table is adapted from Table 5 from the *Wyckoff Steam Injection Treatability Study* (Davis 2002).

gm/ml = gram per milliliter

TABLE 4-3. INTERFACIAL TENSION

Wyckoff OU-1 Preliminary Revised Conceptual Site Model Technical Memorandum

Temperature (°C)	**10**	**20**	**30**	**40**
Average Air/Water IFT (dynes/cm)	70.9	67.7	71.2	69.8
Maximum Air/Water IFT (dynes/cm)	76.8	76.6	74.1	72.3
Minimum Air/Water IFT (dynes/cm)	45.4	62.4	61.6	66.2
Literature Value Creosote/Water IFT (dynes/cm)	50	50	50	50
Average NAPL/Water IFT (dynes/cm)	9.8	10.2	10.9	12.1
Maximum NAPL/Water IFT (dynes/cm)	19.5	22.6	19.7	24.2
Minimum NAPL/Water IFT (dynes/cm)	0.8	2.7	3.6	2.1
Average NAPL/Air IFT (dynes/cm)	36.1	37.4	35.7	33.3
Maximum NAPL/Air IFT (dynes/cm)	41.4	61.8	61.1	35.4
Minimum NAPL/Air IFT (dynes/cm)	32.8	32.5	31.3	29.5
S (average, dynes/cm)	25.0	20.1	24.5	24.4

Notes

S = γgw - γgo - γow

S = surface tension (dynes/cm)

γgw = interfacial tension between groundwater and air (dynes/cm)

γgo = interfacial tension between groundwater and NAPL (dynes/cm)

γow = interfacial tension between NAPL and air (dynes/cm)

TABLE 4-4. WYCKOFF NAPL VISCOSITY (CP) AS A FUNCTION OF TEMPERATURE

Wyckoff OU-1 Preliminary Revised Conceptual Site Model Technical Memorandum

		Viscosity (cP) for Given Temperature			
Sample	**Location**	**10 °C**	**20 °C**	**30 °C**	**40 °C**
99293527	P001	12.4	8.2	6.2	4.7
99293650	RPW-1	17.4	12.1	7.9	6.3
99293652	RPW-3	11.3	7.6	5.7	4.4
99293653	RPW-6	15.8	10.7	7.4	5.6
99293654	RPW-5	14.9	9.8	7.0	5.3
99293656	RPW-8	15.8	8.8	6.1	4.7
99293657	RPW-9	9.9	7.2	5.6	4.5
99293658	RPW-4	4.9	3.9	3.2	2.8
99293651	RPW-1	17.4	11.4	7.8	5.8
99293655	RPW-3	9.1	6.8	4.2	3.4
99293659	RPW-6	5.7	4.4	3.5	2.9

min	4.9	3.9	3.2	2.8
max	17.4	12.1	7.9	6.3
Average	12.2	8.3	5.9	4.6
Standard deviation	4.5	2.7	1.7	1.2

Notes:

This table is adapted from Table 6 from the *Wyckoff Steam Injection Treatability Study* (Davis 2002).

Figure 1-1
Focused Feasibility Study Project Area
Wyckoff OU-1 Focused Feasibility Study

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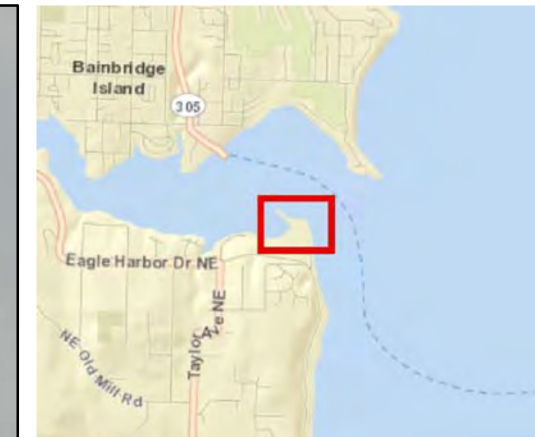

90% or Greater Chance of Encountering NAPL

Wyckoff OU-1 Focused Feasibility Study Project Area

Based on TarGOST Response > 10% RE

Figure 3-1
Estimated Extent of NAPL Product, Plan View – 90% or Greater Chance of Encountering NAPL

Wyckoff OU-1 Focused Feasibility Study

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Figure 3-2
Estimated Extent of NAPL Product, Plan View – 50% or Greater Chance of Encountering NAPL
Wyckoff OU-1 Focused Feasibility Study

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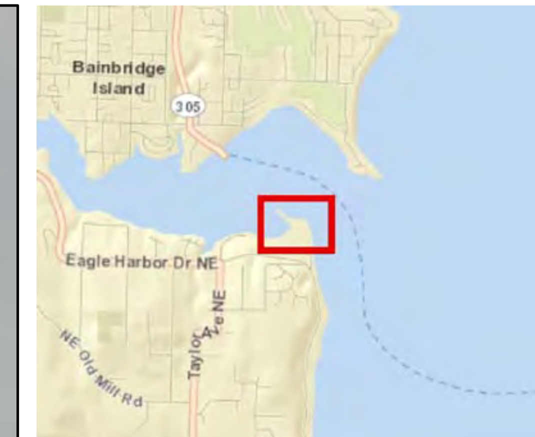


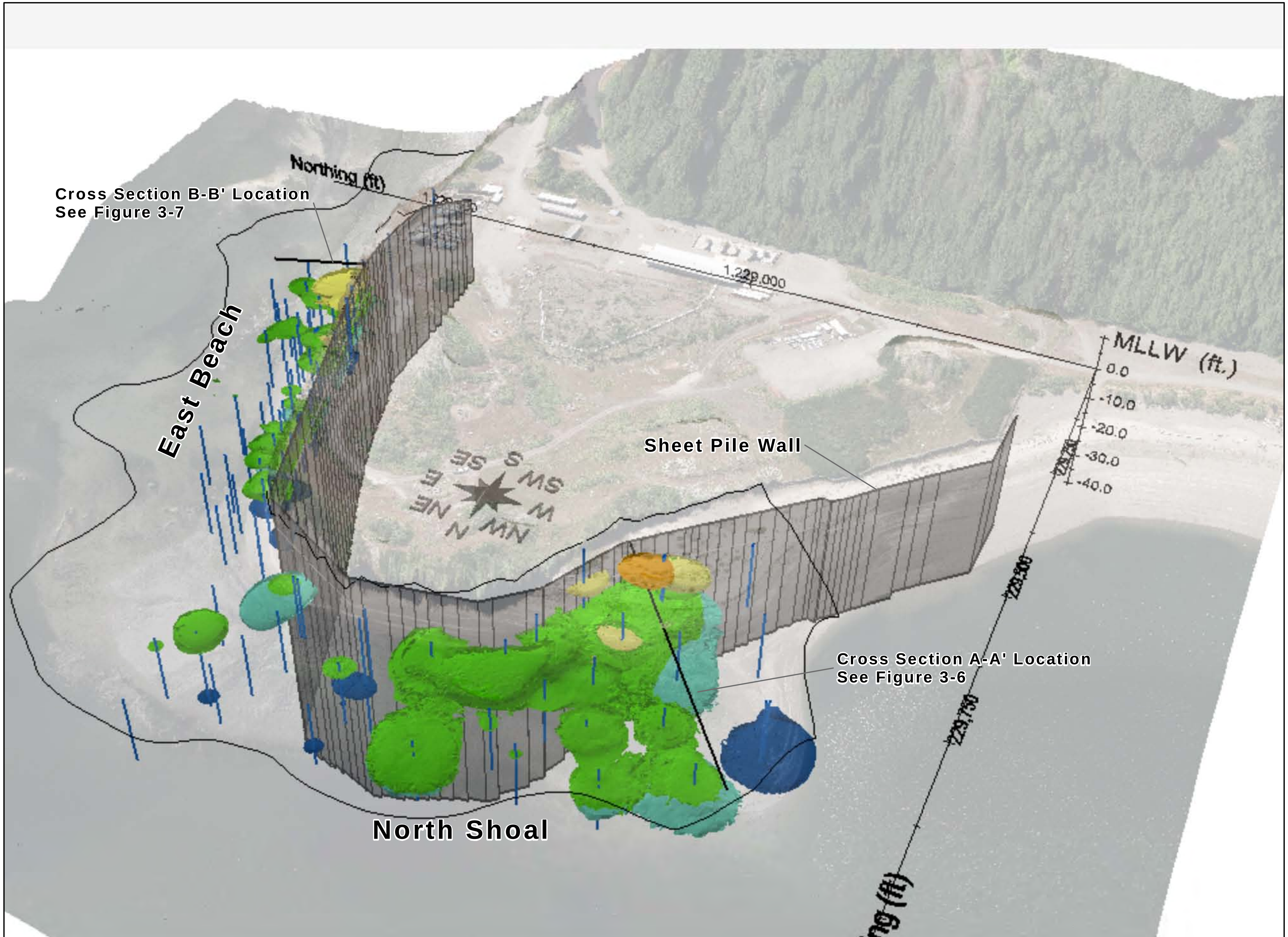
10% or Greater Chance of Encountering NAPL

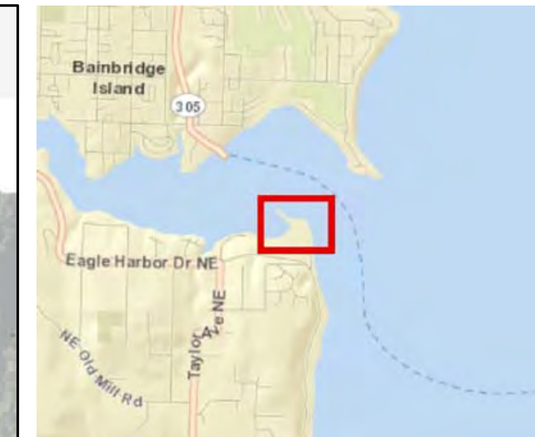
Wyckoff OU-1 Focused Feasibility Study Project Area

Based on TarGOST Response > 10% RE

Figure 3-3
Estimated Extent of NAPL Product, Plan View – 10% or Greater Chance of Encountering NAPL

Wyckoff OU-1 Focused Feasibility Study





Tidal Interval (Elevation Range in Feet, MLLW)

- > HOT (14.5)
- HOT to MHW (14.5 to 10.5)
- MHW to MLW (10.5 to 2.8)
- MLW to LOT (2.8 to -5.0)
- LOT to LOT minus 5 Feet (-5.0 to -10.0)
- < LOT minus 5 Feet

Wyckoff OU-1 Focused Feasibility Study Project Area

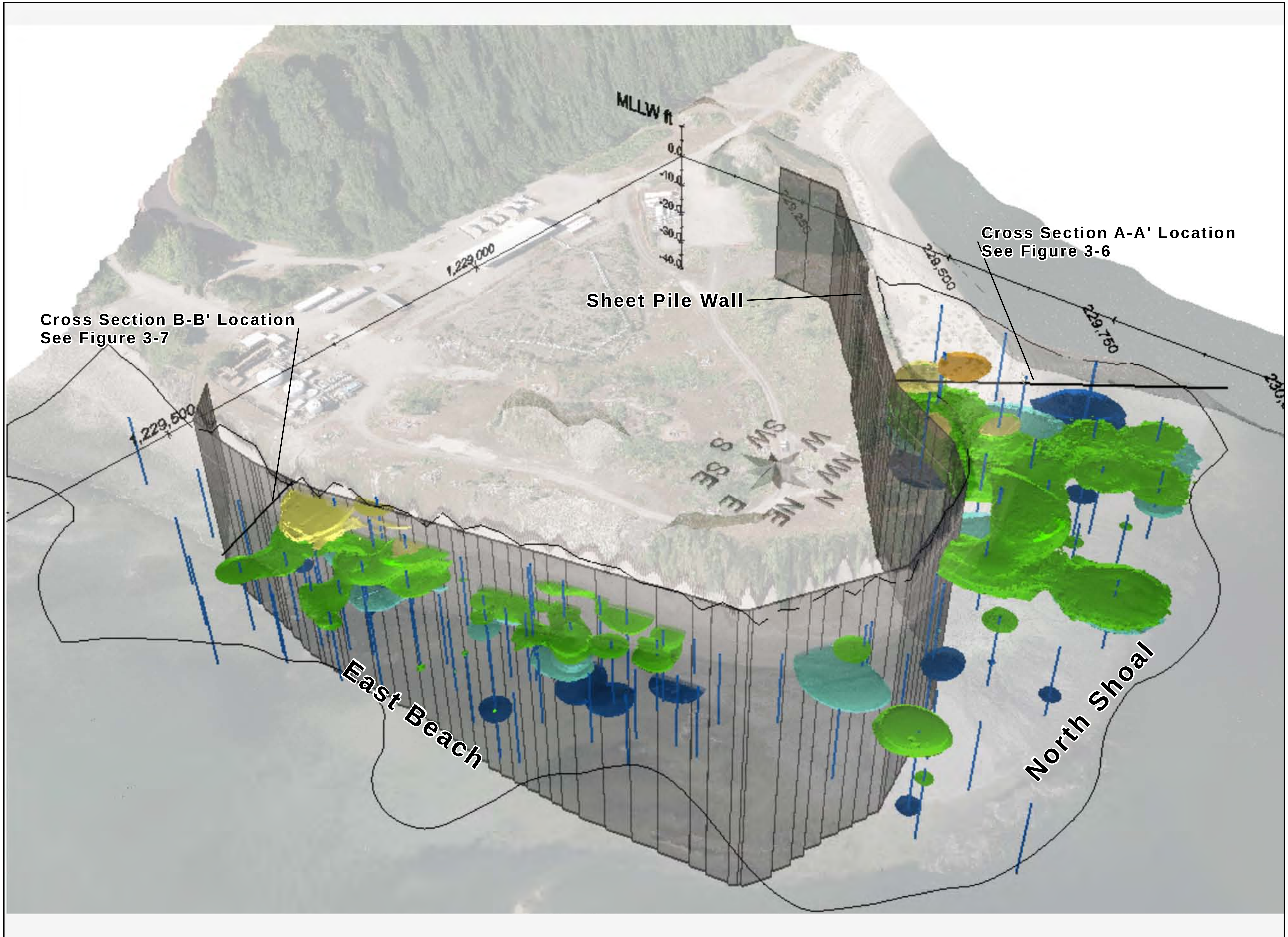
Isosurface indicates 50% or greater chance of encountering NAPL.
Based on TarGOST Response > 10% RE

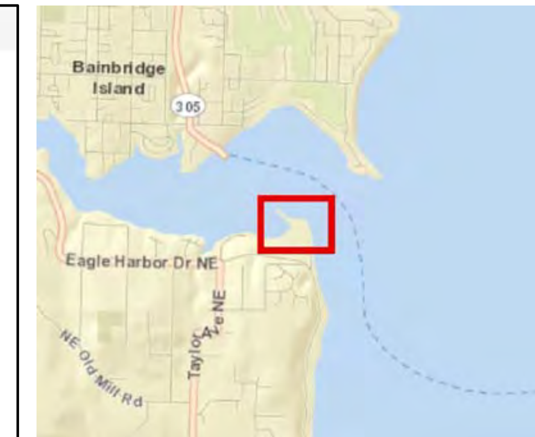
Vertical exaggeration = 5x

MLLW = Mean Lower Low Water
HOT = Highest Observed Tide
MHW = Mean High Water
MLW = Mean Low Water
LOT = Lowest Observed Tide

Figure 3-4
Estimated Extent of NAPL Product, Oblique View from Northwest 50% of Greater Chance or Encountering NAPL

Wyckoff OU-1 Focused Feasibility Study





Tidal Interval (Elevation Range in Feet, MLLW)

- > HOT (14.5)
- HOT to MHW (14.5 to 10.5)
- MHW to MLW (10.5 to 2.8)
- MLW to LOT (2.8 to -5.0)
- LOT to LOT minus 5 Feet (-5.0 to -10.0)
- < LOT minus 5 Feet (< -10.0)

Wyckoff OU-1 Focused Feasibility Study Project Area

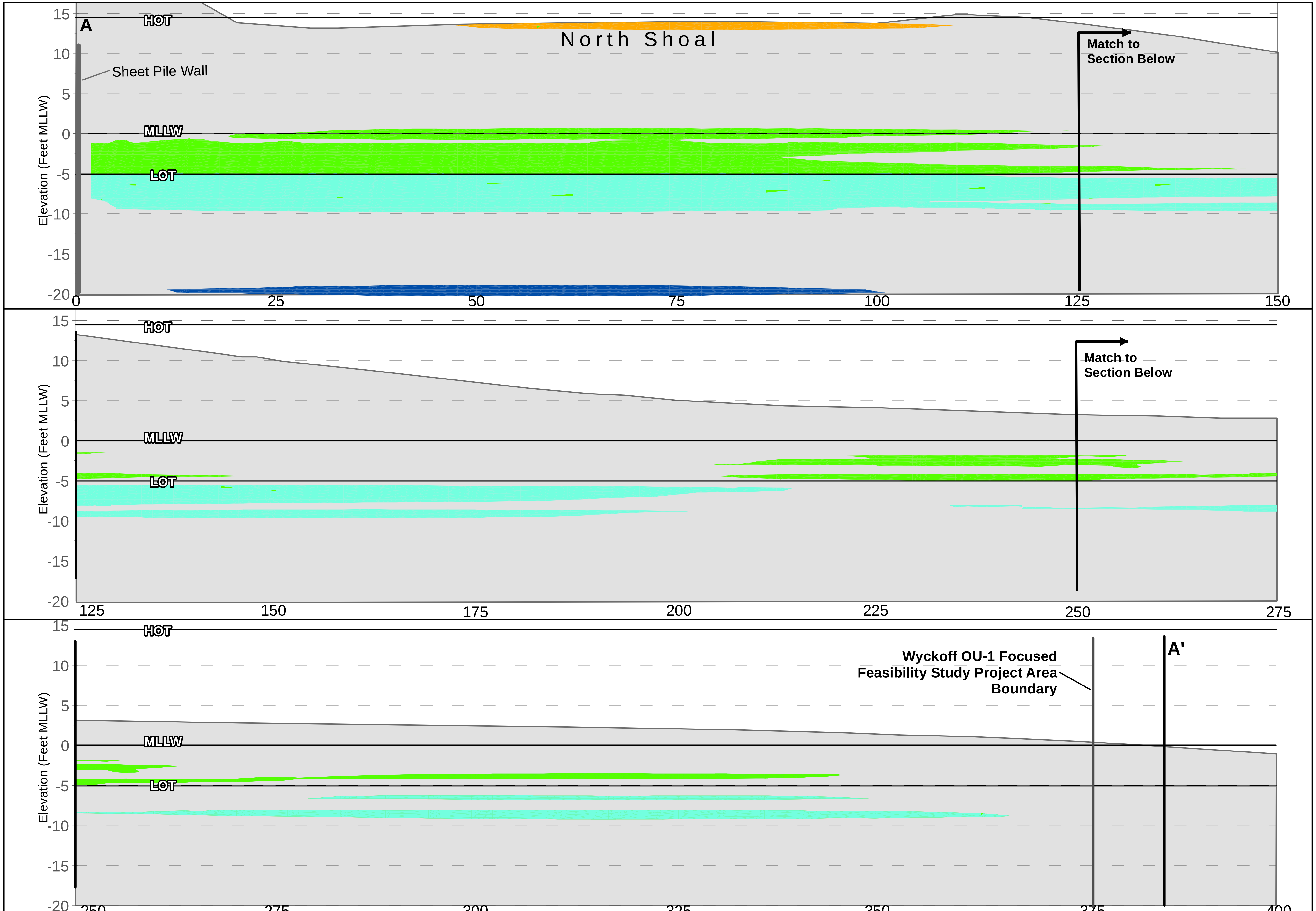
Isosurface indicates 50% or greater chance of encountering NAPL. Based on TarGOST Response > 10% RE

Vertical exaggeration = 5x

MLLW = Mean Lower Low Water
HOT = Highest Observed Tide
MHW = Mean High Water
MLW = Mean Low Water
LOT = Lowest Observed Tide

Figure 3-5
Estimated Extent of NAPL Product, Oblique View from Northeast 50% of Greater Chance or Encountering NAPL

Wyckoff OU-1 Focused Feasibility Study



Tidal Interval (Elevation Range in Feet, MLLW)

- > HOT (14.5)
- HOT to MHW (14.5 to 10.5)
- MHW to MLW (10.5 to 2.8)
- MLW to LOT (2.8 to -5.0)
- LOT to LOT minus 5 Feet (-5.0 to -10.0)
- < LOT minus 5 Feet (< -10.0)

Isosurface indicates 50% or greater chance of encountering NAPL. Based on TarGOST Responses > 10% RE

MLLW = Mean Lower Low Water
HOT = Highest Observed Tide
MHW = Mean High Water
MLW = Mean Low Water
LOT = Lowest Observed Tide

See Figure 3-4 or 3-5 for Cross Section A-A' Location.

Figure 3-6
Cross Section A-A', North Shoal - 50% or Greater Chance of Encountering NAPL

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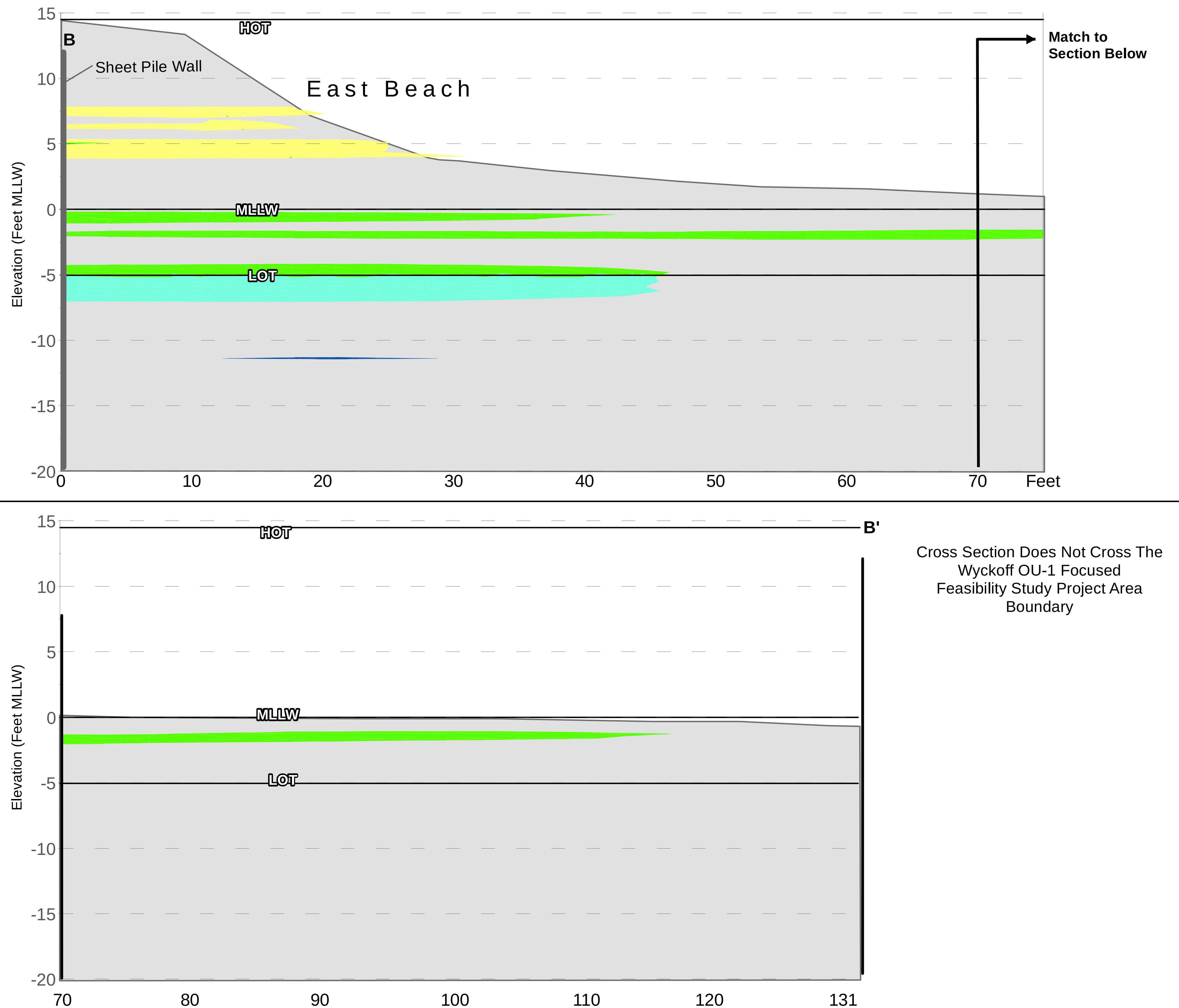

Tidal Interval (Elevation Range in Feett, MLLW)

- > HOT (14.5)
- HOT to MHW (14.5 to 10.5)
- MHW to MLW (10.5 to 2.8)
- MLW to LOT (2.8 to -5.0)
- LOT to LOT minus 5 Feet (-5.0 to -10.0)
- < LOT minus 5 Feet (< -10.0)

Isosurface indicates
50% or greater chance
of encountering NAPL.
Based on TarGOST
Responses > 10% RE

MLLW = Mean Lower Low Water
HOT = Highest Observed Tide
MHW = Mean High Water
MLW = Mean Low Water
LOT = Lowest Observed Tide

See Figure 3-4 or 3-5 for
Cross Section B-B' Location.

Figure 3-7
Cross Section B-B', East Beach- 50% or Greater Chance of Encountering NAPL

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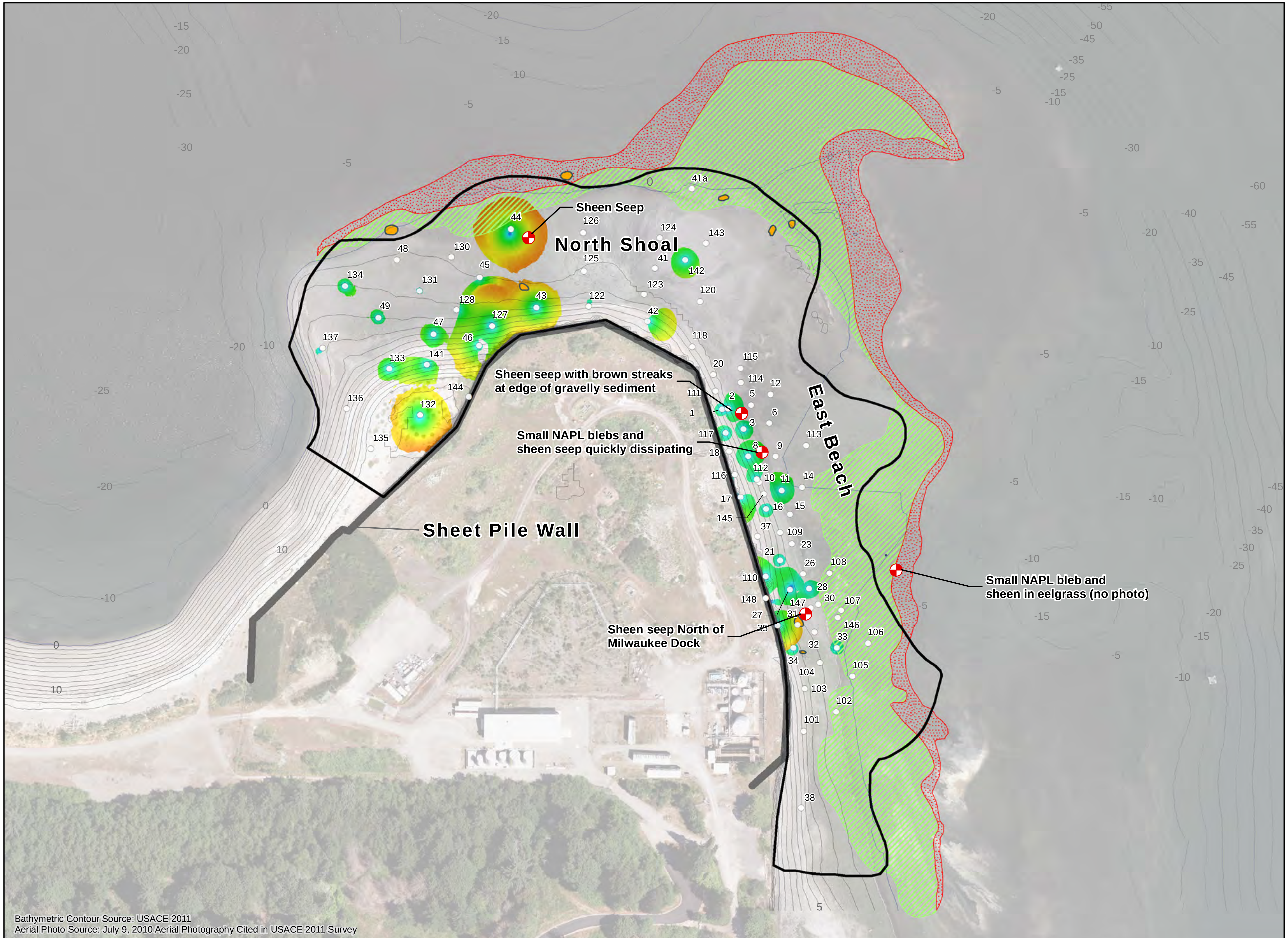

Wyckoff OU-1 Focused Feasibility Study Project Area

TarGOST Response

2012 TarGOST Locations and Numbers

Less Certain

Depicted Areas Represent Relative Uncertainty of Inferred NAPL Volume Based on TarGOST Response Plus or Minus 1 Standard Deviation (SD).

Color Scale Represents SD Range Between 2% RE (More Certain) to 21% Re (Less Certain)

More Certain

Isosurface indicates volume where estimated TarGOST response is greater than 50% Reference Emitter (RE)

Generalized Extent of Eelgrass

Eelgrass

Probable Eelgrass (unconfirmed)

Based on Washington State Department of Ecology Low Tide Site Observations, June 24, 2013

Seeps

Seep Noted by Ecology June 24, 2013

Additional Seep Noted by CH2M HILL June 24, 2013

0 Surface Elevation Contours in Feet (MLLW)
1-foot contour intervals were generated using USACE interpolation methods

2011 survey data provided by USACE

N

0 55 110 220 Feet

Figure 3-8
Uncertainty of TarGOST 50% Response, Plan View
Wyckoff OU-1 Focused Feasibility Study

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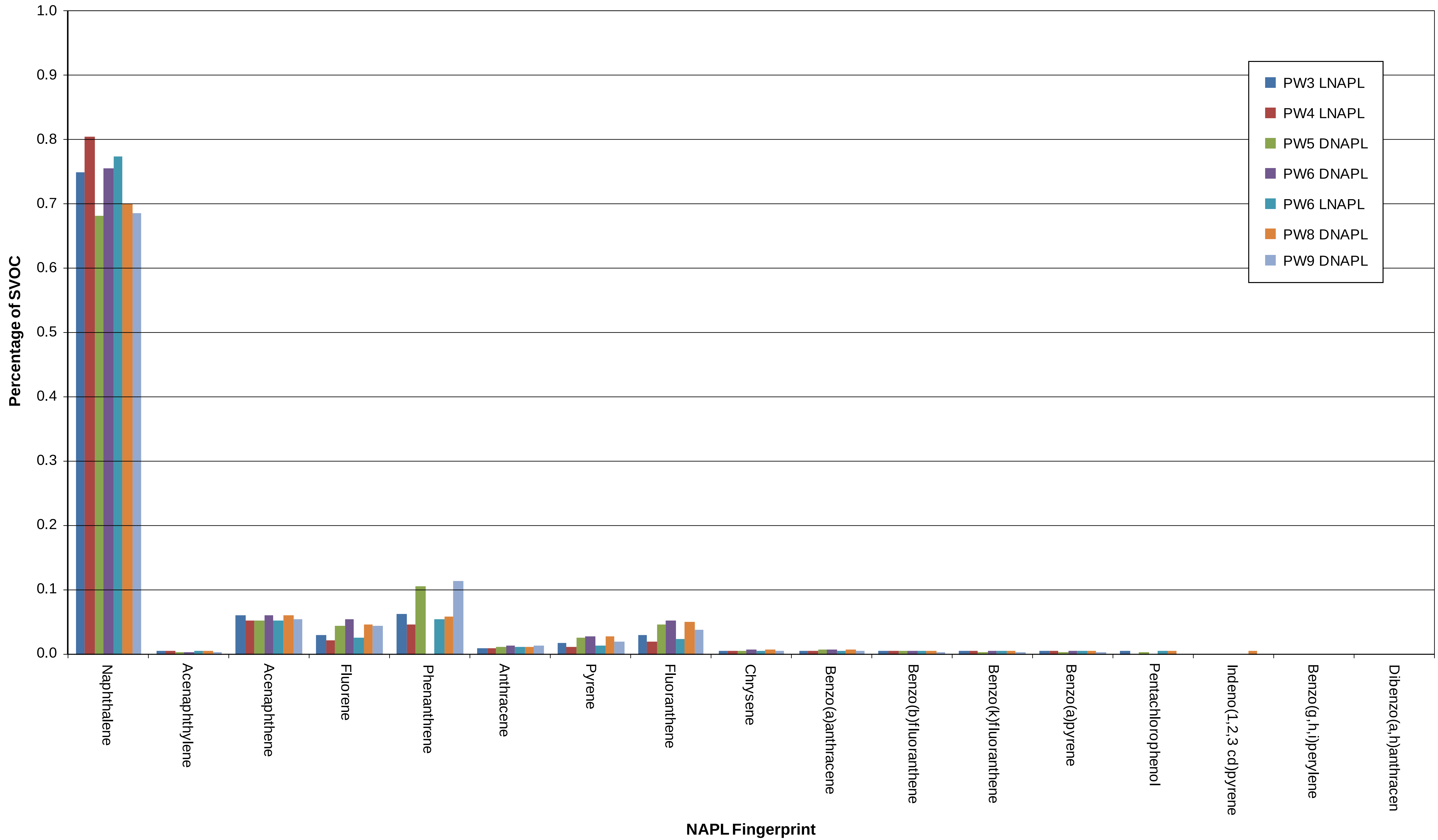

Figure 4-1
Graphical Fingerprint of PAH and PCP Constituents in NAPL Samples
Wyckoff OU-1 Focused Feasibility Study

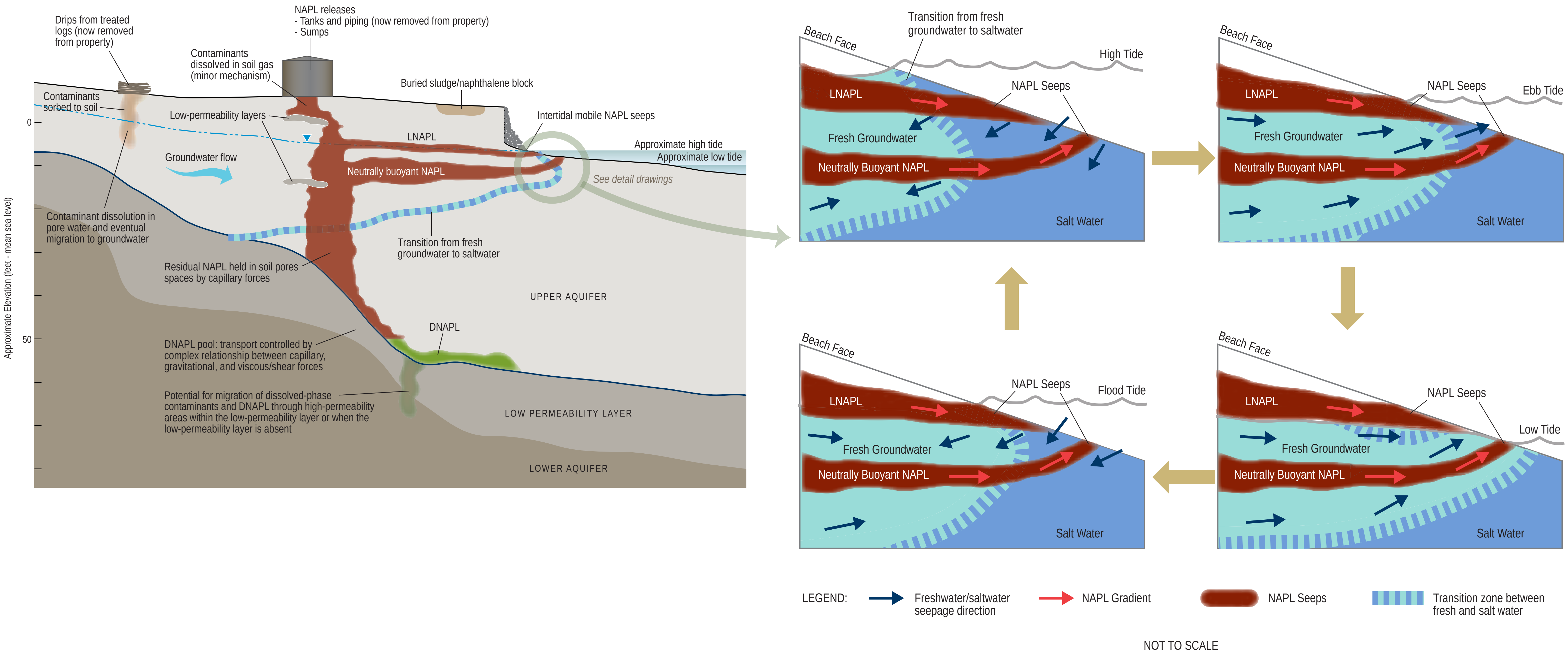

Figure 4-2
Conceptual Site Model Representing Pre-Sheet Pile Wall Conditions
Wyckoff OU-1 Focused Feasibility Study

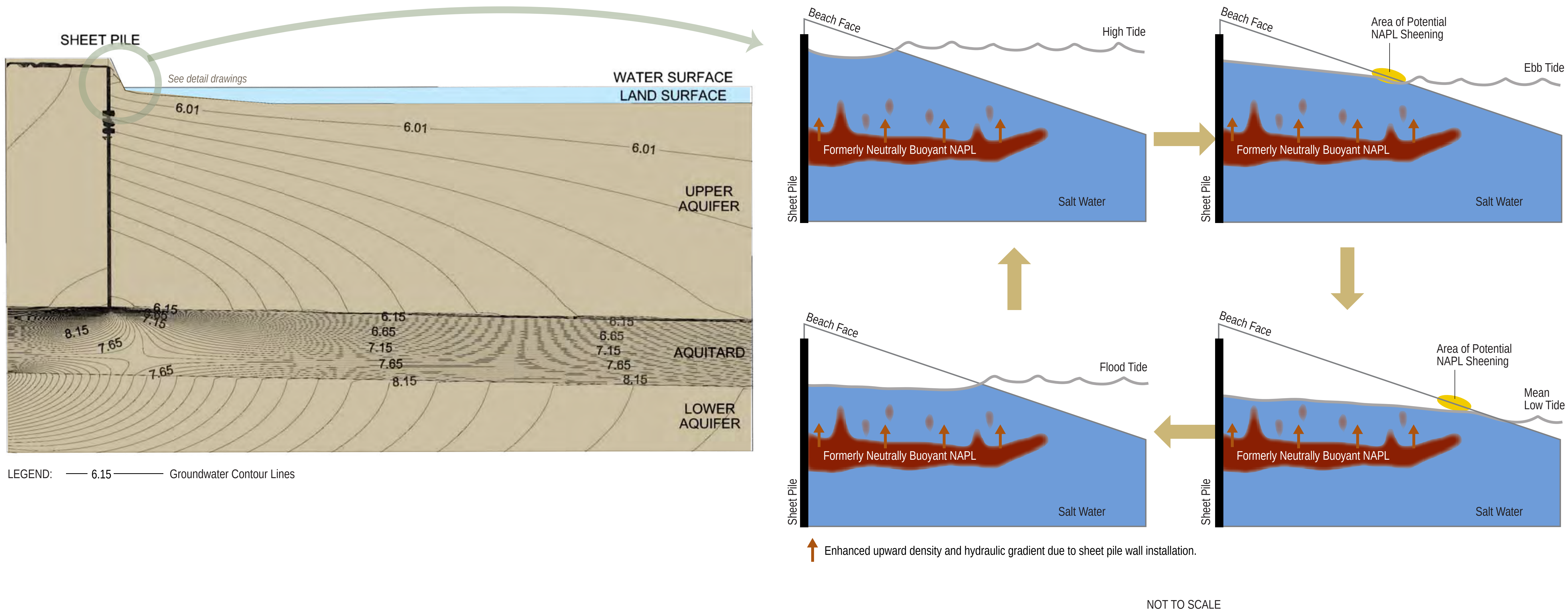

Figure 4-3
Conceptual Site Model Representing Post Sheet Pile Wall Conditions
Wyckoff OU-1 Focused Feasibility Study

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